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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

HUMAN FACTORS ENGINEERING INTEGRATION PROJECT, PHASE I REPORT

By

C. C. Hall, Jr., and J. T. McLane

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PROPULSION AND AUXILIARY SYSTEMS DEPARTMENT

ANNAPOLIS

RESEARCH AND DEVELOPMENT REPORT

July 1976

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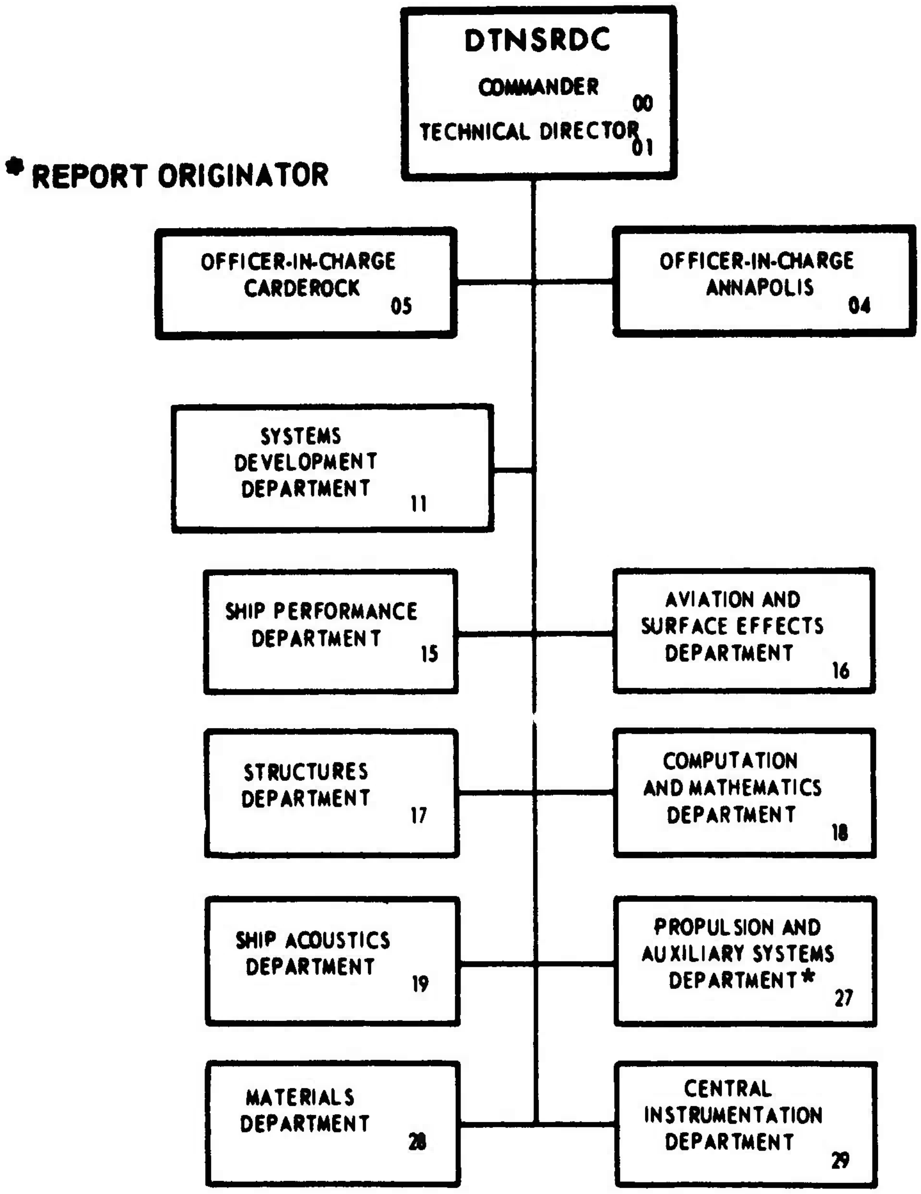
MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



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A study was conducted to develop an initial improved human factors engineering integrated technology. This study was accomplished through the use of a multidisciplined team consisting of in-house Navy, private contractor, and university personnel. The team is concerned with integrating all human factors engineering disciplines and technologies, both existing and currently being developed, which bear upon the human envelope in all stages of the ship (over)

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20. **ABSTRACT** (Cont)

system development cycle from concept formulation to operation. Reported and discussed herein are preliminary analyses of some traditional and nontraditional human factors engineering technologies.

(Authors)

ADMINISTRATIVE INFORMATION

This study was conducted as part of an Advanced Development Program in human factors engineering, Program Element 63707N, Project W43-13, and under the direction of the Naval Air Systems Command (AIR 340F) and Naval Sea Systems Command (SEA 660G). The work was performed by the Systems Effectiveness Branch of this Center under Work Unit 2733-520.

LIST OF ABBREVIATIONS

ADO - advanced development object
PDA - principal development activity
HFEI - human factors engineering integration
HFE - human factors engineering
Co. - company
Inc. - incorporated
CAFES - computer aided function-allocation evaluation system
etc. - and so forth
RDT&E - research development test and evaluation
OR - operational requirement
TLR - top level requirements
TLS - top level specifications
SHAPM - ship acquisition project manager
SES - surface effect ship
i.e. - that is
ILS - integrated logistics support
R&M - reliability and maintainability
T&E - test and evaluation
CNA - Center for Naval Analysis
FBL - functional base line
CBL - conceptual base line
ABL - allocated base line
PHM - patrol hydrofoil missile
HOS - human operator simulator
COR's - circular or requirements
MTBF - mean time between failure
MTTR - mean time to repair
SMDs - ship manning documents
MDM - manpower determination model
FY - fiscal year
GWU - George Washington University
Hz - hertz
D.C. - direct current

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INTRODUCTION

BACKGROUND

During September 1969, an ADO* was issued to address human factors engineering for the first time. That ADO was identified as Human Factors Engineering Technology (ADO 43-13). In 1973, it was revised to include the Human Factors Engineering Technology Integration Project. The Technical Development Plan which responded to that revision addressed the project as follows:

> "Is concerned with integrating all existing and currently being developed HFE disciplines and technologies which bear upon the human envelope in all stages of the ship system development cycle from concept formulation to operation."

As PDA for W43-13, the Naval Air Systems Command (AIR 340F) assigned that project to this Center. The Center views the HFEI project as the development of a very important new technology because it will be a platform level support technology as distinct from a systems or subsystems technology.

As one of its first implementing actions in its role as manager and technical director of the HFEI program, the Center convened a technical workshop on 18-19 June 1974, bringing together a group of nationally recognized scientists from both traditional and nontraditional HFE disciplines. The results of that workshop have been reported[1] and impacts the work that is being reported here.

OBJECTIVE

The overall objective of this advanced development project includes the development of an improved HFE integrated technology to better support Navy program managers and design engineers in implementing the total ship planning and acquisition process, and the demonstration, in quantitative terms, of the degree of improvement achieved through the application of that new technology.

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*Definitions of abbreviations used are on page i.

[1] Superscripts refer to similarly numbered entries in the Technical References at the end of the text.

APPROACH

To achieve the stated objective, a multidisciplined team consisting of the following in-house Navy, private contractor, and university personnel was established:

- DTNSRDC
- Boeing Aerospace Co.
- W. D. Teague, Inc.
- Essex Corporation
- GWU (Dr. Henry Solomon)
- U of Md (Dr. Harriet Trader)
- NELC

Each of these team members was charged with conducting a task integral to the total HFEI project; brief descriptions of the tasks are given below.

DTNSRDC

This Center provided technical direction to the other participants in the HFEI program and provided an input to the initial integration scheme in the form of a preliminary description of the ship design process.

As the technical director for HFEI, this Center was responsible for arranging for contracts with the other participants, scheduling and conducting progress meetings with the project participants and the program managers (NAVAIR, NAVSEA), ensuring timeliness and accuracy of products from contractors, and solving project-related problems that arose as a consequence of the progress meetings.

As one of the technical participants in the HFEI project, this Center provided a preliminary description of the Navy's ship design process to be used in determining the generalizability of HFE technologies across platforms and classes of problems.

BOEING AEROSPACE CO.

Boeing Aerospace Co., Seattle, Washington, was tasked to adapt the CAFES project to ship system development. CAFES, which is another part of the ADO, is described as a first generation system of integrated computer aids to HFE functions for design, development, and operations of man-machine systems, primarily air systems.

WALTER DORWIN TEAGUE ASSOCIATES, INC.

Walter Dorwin Teague an Associates is an industrial design firm headquartered in New York, New York. They were tasked to provide a profile of the industrial design field and relate those tools, techniques, methodologies, etc., to HFE.

ESSEX CORPORATION

Essex Corporation, Alexandria, Virginia, was selected to be the integration contractor. The primary role of the integration contractor was to provide technical analysis and planning support to this Center in developing a first approximation of the HFE integrated technology by including inputs from all of the program participants. Additionally, Essex was tasked to provide an assessment of HFE practices in commercial shipbuilding and to review current technologies in the fields of manpower, personnel and training, and medical and life support for their inclusion in the first approximation.

GEORGE WASHINGTON UNIVERSITY

Dr. Henry Solomon, Dean of the Graduate School of Arts and Science, at the George Washington University, Washington, D. C., was tasked to provide a profile of the field of economics including the tools, techniques, methodologies, etc., and to identify those items that have possible applications to solving HFE problems.

UNIVERSITY OF MARYLAND

Dr. Harriet P. Trader, Assistant Dean of the School of Social Work, University of Maryland, Baltimore, Md., was tasked to provide a profile of the area of social research identifying the tools, techniques, methodologies, etc., associated with the field and highlighting those that might relate to HFE.

NAVAL ELECTRONICS LABORATORY CENTER (NELC)

The Human Engineering Division (Code 3400) at NELC was tasked by this Center to assess the human engineering speciality and identify pertinent tools, techniques and methodologies related to ship system design.

DISCUSSION

Each of the program participants completed the assigned tasks and submitted reports to this Center. After reviewing the reports, this Center forwarded them to the integration contractor for inclusion in the report on the first approximation. A discussion of each participant's technical effort follows. The effort by this Center is reported in its entirety, while all other efforts are discussed in summary form.

Fundamental to this project is first the recognition that the Navy is making important progress toward improving the total ship planning, design, and acquisition process, and second that there is a body of HFE technology which can be integrated for incorporation into the new technology. Previous HFE technology development and technology transfer projects have addressed equipments and/or selected functions of Navy surface ships but not the platform and the optimization of its full operational capability. Within the limited effort of the initial phase of this project it appears that the generalizability of HFE technologies across platforms and classes of problems is very feasible and will significantly enhance the evolving ship planning, design, and acquisition process.

Description of the Total Ship Planning Design and Acquisition Process

Since the HFEI project is a new technology project, it inherently contains the potential of information transfer to the broad Navy RDT&E management process. This section of the report therefore will briefly outline the RDT&E management process as an introduction to discussing the details of the total ship process and the relationship of the HFEI to the ship process.

A functional view of the Navy RDT&E management process is given in figure 1 which is explained below:

- Block 1 represents the development of a storehouse of knowledge by research. This knowledge is considered to be essential to the development of new technologies. It represents predictions concerning technological capabilities and should be accompanied by information on the problems of attaining those capabilities.

- Block 2 represents the development of the technological base upon which advanced systems will rest.

- Block 3 represents the initial use of new technologies. It involves experimentally demonstrating the feasibility and cost of combining technologies into technological building blocks. It is the beginning of the innovative process. The major product of this effort is proof of the advantage to be gained through the application of new technology as well as a clearer recognition of the additional new technology which will be required for an advanced system.

- Block 4 represents the functions of engineering development and operational systems development. These functions are of innovation not invention. The new technology must have been developed through effective research and exploratory development before it can be exploited in systems development.

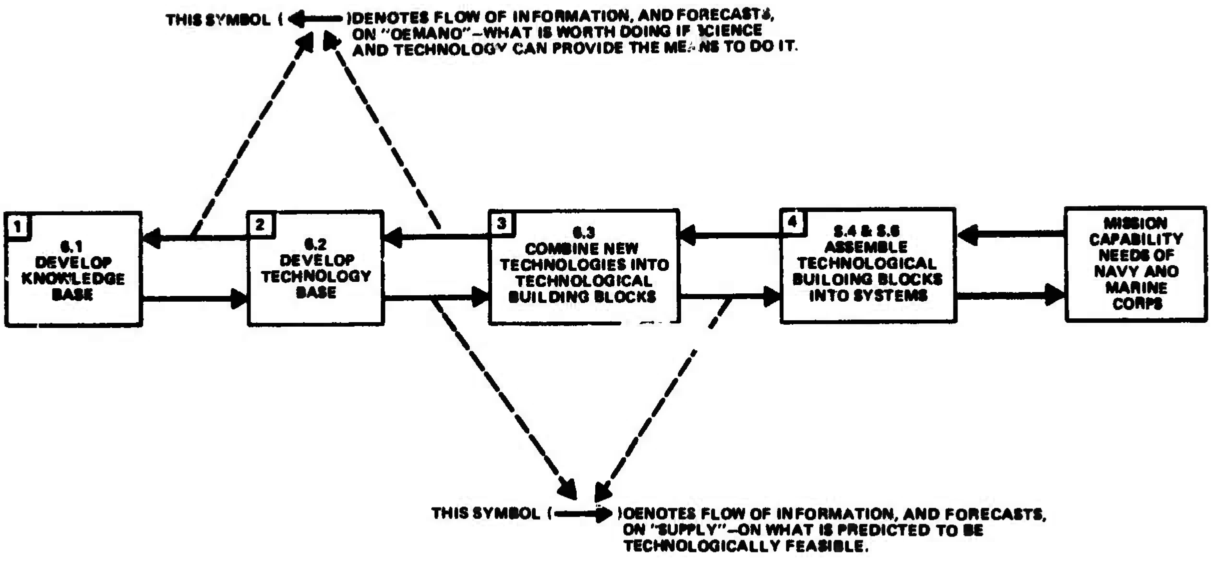

Figure 1
Functional View of the Defense RDT&E Process

The HFEI task is a prime example of the type of operation that takes place during the process outlined in block 3 in figure 1. It will integrate technologies, provide information feedback (technical gaps and forecasts) to the technology base of block 2, and provide technical information (demonstrate technical feasibility) to the system building blocks (ship design process) referred to in block 4.

Within that larger management process, the ship planning, design and acquisition process is generally considered to consist of the following three major stages:

- "Need" identification or requirement derivation.
- Design stage.
- Production stage.

The requirement and the design stages will be discussed below; the production stage (commercial shipbuilding) will be addressed in a later section.

Requirement Derivation

For combatant ships the requirement derivation stage is initiated with threat and force level analyses, force mix analyses, mission effectiveness analyses for given scenarios, and other operations analyses. These studies fall under the direct cognizance of CNO and they are conducted by OPNAV supported by CNA; under the direction of CNO these studies may also be conducted by Naval technical agencies proficient in operations analyses. The studies require certain assumptions to be made regarding features of the evolving ship concept. Hand-in-hand with the operations analyses, therefore, ship feasibility studies are developed which contribute technical inputs regarding ship size, cost, and capabilities to the operations analyses. Such studies will be called prefeasibility studies from here on to differentiate them from the feasibility studies developed in the Naval Material Command (NAVSEA) later in the ship process. For monohull displacement ship concepts, these prefeasibility studies are generally developed by CNA with the computer synthesis model "CODE SHIP."

All of these studies result in the development of an OR document and in an understanding as to the ship type and approximate size desired.

In the ensuing ship process, the Naval Material Command is generally called upon to develop other feasibility studies aimed at supporting the process of defining the major system level requirements for the new ship. Cost versus capability tradeoffs are examined through the development of a matrix of feasibility studies which vary payload, protection, and platform performance features.

The actual process leading to the selection of a concept is illustrated in item (a), figure 2. Termination of that process constitutes the end of the requirement derivation.

The actual process leading to the selection of a concept is illustrated in item (a), figure 2, which attempts to give some indication of the many actions, interactions, and reiterations that occur. A simplified version of that same process is given in item (b), figure 2.

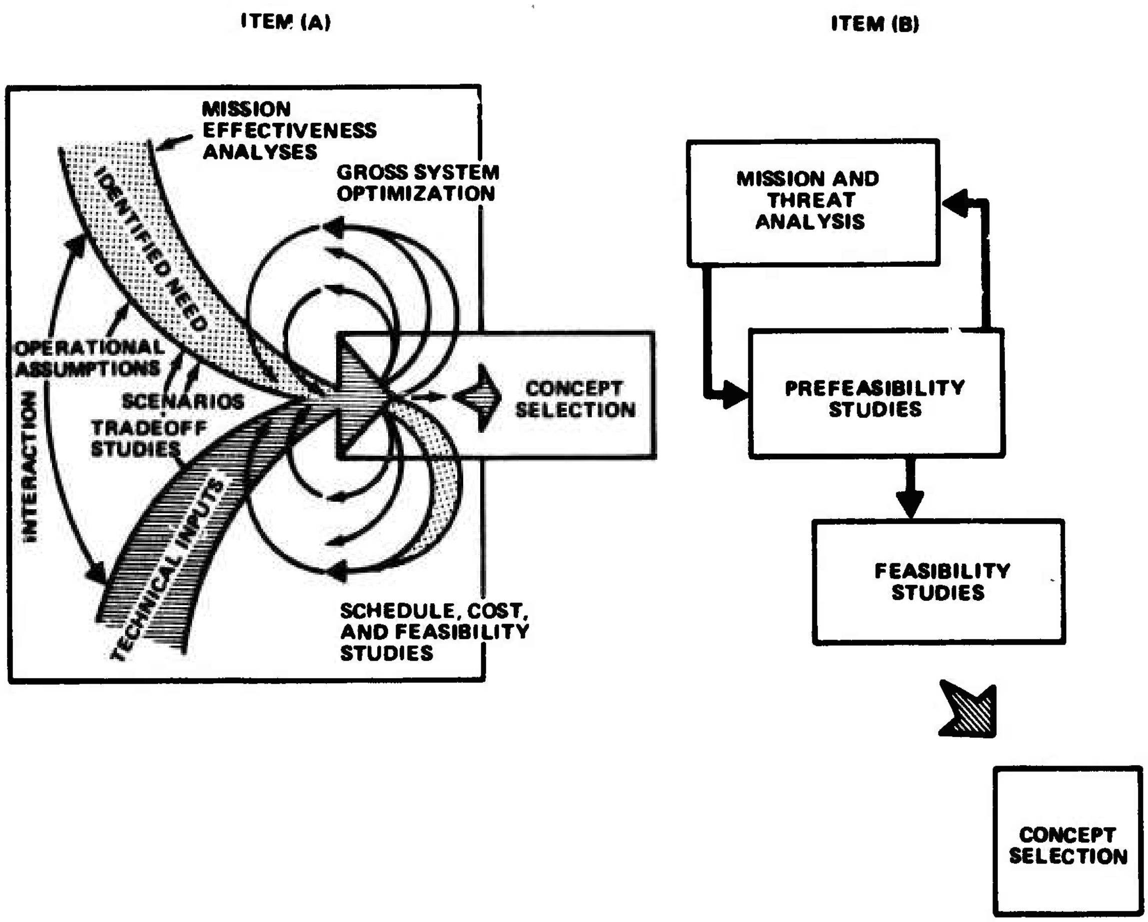

Figure 2
The Concept Selection Process

In a formal sense the ship design process begins immediately following the selection of a ship concept. In actual practice, however, the prefeasibility and feasibility studies frequently contain information or data resulting from ship design activities/studies. This "gray area" between the requirement derivation stage and the design stage is reflected in figure 3 which is an overview illustration of the ship planning, design, and acquisition process. Figure 3 also shows the major milestones for that process and those groups having primary cognizance for the individual phases of the process.

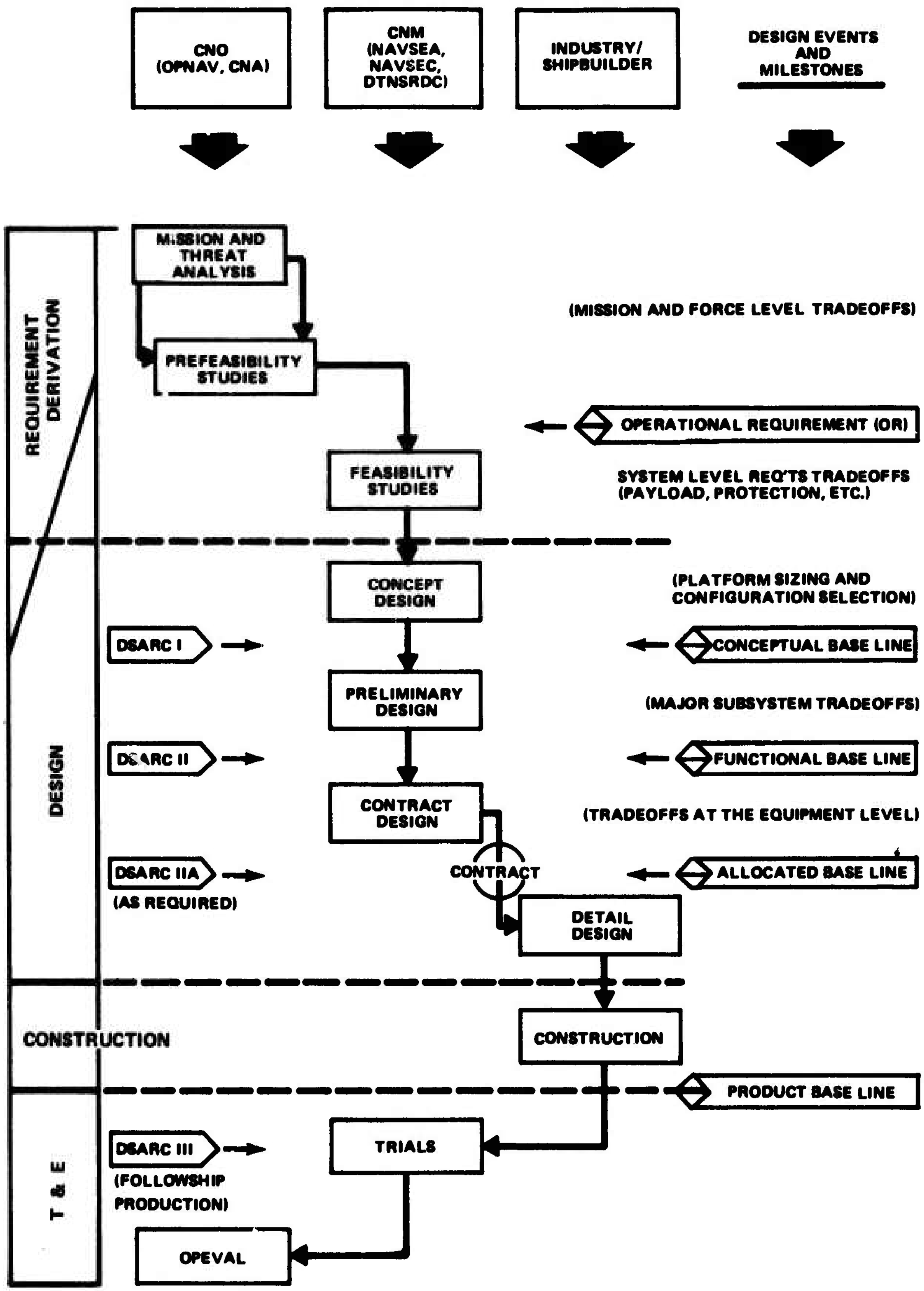

Figure 3
Ship Development Process-Overview

Ship Design Phase

For purposes of this report the Navy ship design process is considered to consist of the following phases:

- Feasibility studies.
- Concept design
- Preliminary design
- Contract design.

Feasibility studies are first performed to establish cost/characteristics tradeoffs to determine how costs will vary with such features as speed, endurance, and major elements of the military payload. The next step, conceptual design, resolves technical risks associated with the concept and defines the ship in terms of overall geometry, weight, type of propulsion machinery, speed, and endurance; also a class cost estimate is made. The CBL includes a draft of the TLR which essentially apprise CNO of the cost of a ship that will meet the operational requirement.

After review and acceptance, the CBL becomes the input to the next step in the process, the preliminary design phase. Its product, the FBL, comprises about 40 drawings, an equipment list, a manning document, and final drafts of the TLR and TLS. These latter two documents include drawings and studies and are formally defined as the FBL. In conjunction with the other items, they become the input to the contract phase of the other design process.

The last phase of the design process is the contract design phase. The output of this phase is called the ABL and comprises approximately 65 drawings, detail specifications, updated versions of the TLR and TLS, and about 70 additional diagrams, reports, and guides. This ABL defines the ship in sufficient detail for a builder to make an intelligent bid on the time and cost required to construct one or more ships.

At this point, the direct Navy participation in the design process is interrupted and may be terminated. The next step in the process is the detail design phase which is the responsibility of the shipbuilder after he is awarded a contract for one or more ships. The Navy involvement in detail design is primarily one of review and approval or, when a lead ship and follow ships are called for in the procurement process, the development of a follow ship ABL.

The objectives, products, and processes of each of the previously described design phases as conducted by the Navy are given in table 1. Another, more complete listing of the products especially as they are deliverables to a ship acquisition project manager is given for each of the design phases in tables 2, 3, and 4. Spaulding and Johnson presented further information on this subject.[2]

TABLE 1
SHIP SYSTEM DESIGN

Objectives	Products	Process
	Conceptual Phase Feasibility Studies	
a - To define a series of feasible ships, with associated production costs, which meet, or approach, initial performance requirements. b - To achieve a balance between operational requirements (based on companion military effectiveness studies) and production costs (i.e., to determine most operationally cost effective alternative). c - To select, from the alternative defined, a ship for conceptual design ("concept selection"). d - To assure definition of alternative ships to the level required for a class E (class F for less reliable results) cost estimate. e - To identify the major technical risks associated with alternative ships.	a - "Concept selection." b - Class E or F cost estimate. c - Definition of payload. d - Synthesis model weight (1 digit level) space allocations (developed by hand if synthesis model not available). e - General arrangements drawings (if a "hand study"). f - Complement (officers, CPO's, and enlisted). g - Type of machinery and number of propellers. h - Speed. i - Installed electric power. j - General ship geometry including total ship volume and area estimates. Above items are included in the Feasibility Report.	a - Small group effort (3-4 people). b - Synthesis model (50-300 ships or "hand (2-30 ships) analysis" (5% accuracy on ships weights). c - Cost program operates on synthesis on hand study outputs. d - General arrangements drawings developed with hand studies. e - Performance in terms of speed, endurance, major payload items, and special features (side protection, etc.). f - Relative accuracy and consistency versus "absolute' nature of results is stressed. g - For non state-of-the-art designs, basic design methodology must be developed prior to that of feasibility studies.
	Conceptual Phase Conceptual Design	
a - To provide a technical base line (conceptual base line (CBL) for DSARC I for new major combatant or developmental designs. b - To assure definition of the ship to the level required for a class D cost estimate (provides a basis for setting a design-to-cost goal by OPNAV). c - Validation of feasibility study results, provision of a firm base line for initiation of preliminary design (size, weight, and cost should only be "reduced" in preliminary and contract designs). d - Initial resolution of major technical risks identified in the feasibility studies.	a - Class D cost estimate. b - Draft TLR. c - Conceptual base line (CBL) package 1. Design rationale 2. General arrangement drawings. 3. Weight estimate at 3 digit level. 4. Body plan. 5. Transverse and damage stability. 6. Speed/power curve. 7. Structural midship section (optimal). 8. Tentative combat system block diagram. 9. Preliminary weapons equipment list. 10. Manning list. 11. Preliminary master equipment list. 12. Propulsion/propeller analysis. 13. Preliminary machinery arrangement. 14. Power analysis and tentative generator selection. 15. Auxiliary machinery analysis. 16. Preliminary electronics space and topside arrangements.	a - "Team effort" (15-25 people). b - Continual interaction with TLR development (military effectiveness studies in parallel). c - Ship sized on an "absolute" basis versus "relative" basis in feasibility studies. d - Major subsystem tradeoffs. e - Development of credible space/weight budget. f - Emphasis on resolution of major technical risks.

	Preliminary Design	
a - To provide a technical base line (functional base line (FBL)) for DSARC I or II. b - To assure definition of the ship to the level required for a class C cost estimate (lowest budget quality estimate). c - To achieve a complete engineering description of an integrated ship system such that the basic ship size and definition will not change during contract design. d - To achieve functional definition of integrated subsystems selected for optimization of total ship performance and cost. e - To select final design criteria for whole ship entity characteristics such as noise and ship protection consistent with cost and performance optimization of the total ship.	a - Class C cost estimate. b - TLS (top level specification). c - Planning documents 1. ILS plan 2. Combat system management plan 3. Hand based test site management plan (if required) 4. T&E master plan d - FBL package 1. Master equipment list (MEL) 2. Preliminary ship manning document 3. Noise evaluation and ship protection analysis 4. RMA analysis 5. Structural analysis and drawings 6. General arrangements 7. Space arrangements 8. Access studies 9. Habitability studies 10. Weight estimate 11. Stability analysis 12. Resistance/seakeeping/maneuvering analysis and model tests 13. Propulsion system analysis 14. Electrical system analysis 15. Machinery and auxiliary arrangements 16. Preliminary descriptive system analysis 17. HVAC requirements and diagrammatics 18. Deck and weapons system analyses and drawings 19. Ship control analysis 20. Combat data document 21. Combat system block diagrams and analysis 22. Combat system description 23. Combat system space arrangements 24. IC, navigation, radar, IFF and sonar analysis 25. Antenna arrangements and topside design performance assessment 26. External communications and command and control description	a - Major effort (80 people). b - Design-to-cost tradeoff analysis "design review" and selection. 1. Subsystems ● Hull form ● General arrangements ● Electric power ● Propulsion system ● Auxiliary systems ● HVAC ● Deck and weapons handling and replenishment systems ● Ship control ● Structures ● Ship manning ● Weapons and sensors ● Antennas and topside design performance 2. Ship Entity Characteristics ● Noise and vibration ● Ship protection ● ILS/RMA c - Intensive ship system level integration/optimization analysis. d - Focus on TLS development. e - Combat systems integration with ship system. f - "Design freeze" at completion of subsystem and ship entity characteristics selection.
	Contract Design	
a - To provide a technical/contractual base line (allocated base line (ABL)) suitable for DSARC II or III. b - To assure definition of the ship to the level required for a class B and/or class A cost estimate (validation of "design-to-cost"). c - Complete translation of the FBL "engineering" definition of the ship to a contractual "biddable package". d - General validation of FBL ship system and subsystems through increased level of definition.	a - Class B and/or class A cost estimate. b - Ship specification. c - Planning documents for detail design and construction phase (further developments of plans listed under Preliminary Design Products. d - ABL package (contract, contract guidance, and study drawings with selected studies and guidance documents). Consists generally of updates and further developments of preliminary design products with the addition of 30-40 drawings and system diagrams and several studies which provide more detailed definition of subsystems. e - "Backups" analytical studies, not provided to shipbuilder. f - GFE procurement specifications. g - GFI requirements definition. h - Contract data requirements package. i - Preliminary operational stations booklet. j - Mock-ups.	a - Major effort (120 people). b - Emphasis on: 1. Preparation of ship specifications 2. CDRL package preparation 3. Contractability and producibility of ABL package 4. GFE/GFI definition c - Detailed subsystem/sequipment definition. d - Final system performance validation by model tests. e - Detailed space layouts. f - Mock-up evaluation of such spaces as bridge and office complex. g - Intensive final package review and adjudication effort. h - Formal configuration control.

TABLE 2
TYPICAL CONCEPTUAL BASE LINE PACKAGE DELIVERED TO SHIP ACQUISITION PROJECT MANAGER AS A RESULT OF CONTRACT DESIGN

Feasibility Study Report	Conceptual Design Final Report
Complement (officers, CPO, enlisted)	Draft of top level requirements
Light ship weights and moments	Design rationale
Load weights and moments	Gross general arrangement drawings
Full load displacement	Weights and moments
Type of machinery	Rough body plan
Number of propellers	Speed and power curve
Speed and power - two conditions	Structural midship section
Installed electrical power	Tentative combat system block diagram
Linear dimensions of ship	Tentative weapons and electronic equipment list
Hull and superstructure areas and volumes	Output of manpower determination model
	Special studies in peculiar or risk areas

TABLE 3
TYPICAL FUNCTIONAL BASE LINE PACKAGE DELIVERED TO SHIP ACQUISITION PROJECT MANAGER AS A RESULT OF PRELIMINARY DESIGN

Arrangement Drawings
Configuration control
Space and equipment arrangements for:
• Damage control central
• Workshops
• Control station
• Radar rooms
• Air navigation and ESM/ECM room
• Computer room
• Sonar equipment rooms
• Bathythermograph and nixie room
• Combat information center
• CIC equipment room
• Gun and missile fire control room
• Launcher control room
• Missile fire control radar room
• Missile computer room
• Gun fire control radar room
• Gun mount power room
• Interior communications rooms
• Ship entertainment room
• Communications center and radio transmitter room
Main and auxiliary machinery
Shafting
Intake and uptake systems
Anchoring, mooring, and towing
Towed systems
Boat stowage and handling
Special handling systems
Replenishment at sea and stores handling
Weapons and ammunition handling and stowage
Aircraft facilities
Topside antenna systems

Structural Drawings
Midship section
Shell expansion and typical sections
Scantlings - decks and platforms
Scantlings - superstructure

Hull Form Definition Drawings
Curves of form, cross curves, and Bonjean curves
Lines drawing
Rudder and appendage configuration

System Definition Diagrams
D.C. systems to be controlled/monitored in D.C. central
60 Hz power distribution system
Special frequency power distribution system
Heating ventilation and air conditioning
Stores flow
Combat system functional flow
Combat system operational sequence
Radar, IFF, and tactical data system
ESM/ECM air navigation and infrared systems
Sonar system
Weapons system
Weapons system interface
Exterior communications system

Documents
Top level specifications
Master equipment list
Controlled equipment list
Schedule a input
GFI/GFE matrix
Preliminary ship manning document
Ship vibration report
Airborne noise report
Radiated and sonar self-noise report
Preliminary design weight estimate
Ship specification study
Combat data document
Combat system functional description
Combat system functional listing
Combat system analog interface requirements
Combat system digital interface requirements
Alarm, data display and navigation signals transfer requirements
Voice communication transfer requirements
Ship control console requirements
Navigation interface requirements
Intra-ship communication station tabulation
ICAN test requirements

TABLE 4
TYPICAL ALLOCATED BASE LINE PACKAGE DELIVERED TO SHIP ACQUISITION PROJECT MANAGER AS A RESULT OF CONTRACT DESIGN

Arrangement Drawings
Configuration control
Space and equipment arrangements for:
• Damage control central
• Workshops
• Control station
• Radar rooms
• Air navigation and ESM/ECM room
• Computer room
• Sonar equipment room
• Bathythermograph and nixie room
• Combat information center
• CIC equipment room
• Gun and missile fire control room
• Launcher control room
• Missile fire control radar room
• Missile computer room
• Gun fire control radar room
• Gun mount power room
• Interior communications room
• Ship entertainment room
• Communications center and radio transmitter room
Main and auxiliary machinery
Shafting
Intake and Uptake Systems
Anchoring, mooring, and towing
Towed systems
Boat stowage and handling
Special handling systems
Replenishment at sea and stores handling
Weapons and ammunication handling and stowage
Aircraft facilities
Topside antenna systems
Machinery space noise treatment
Tank arrangements and capacities
Machinery shipping and accessibility
Auxiliary equipment and fluid systems
Steering system
Stabilization systems
Maneuvering systems
Hauldown traversing system
Aircraft handling and stowage
Ship control console configuration

Structural Drawings
Midship section
Shell expansion and typical sections
Scantlings - decks and platforms
Scantlings - superstructure

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Radar, IFF & tactical data system
ESM/ECM air navigation and infrared systems
Sonar system
Weapons system
Weapons system interface
Exterior communications system

Documents
Master equipment list
Controlled equipment list
GFI/GFE matrix
Preliminary ship manning documents
Contract design weight estimate
Ship specifications
Ship contract data requirement package (CRDL)
RAS, FAS design study and replenishment rate analysis
Tactical data system operation & test program
Preliminary operational stations booklet
Combat data document
Combat system functional description
Combat system functional listing
Combat system analog interface requirements
Combat system digital interface requirements
Alarm, data display & navigation signals transfer requirements
Voice communication transfer requirements
Ship control console requirements
Navigation interface requirements
Intra-ship communication station tabulation
ICAN test requirements
Exterior communications system description
HFEI requirements

Cost

Another important facet of ship design is the cost studies that occur during all phases of the design process. A brief description of cost and its relationship to the design process is given below. This information was obtained from the instruction.[3]

Cost analysis calls for the development of acquisition, operating, and life-cycle cost models for the ship and marginal cost factors on a unit basis for use in making cost-control tradeoff studies. These analyses, conducted during both preliminary and contract design phases, are used by the ship design manager to control the ship configuration as necessary to stay within the design-to-cost goals. Configuration control is the responsibility of the ship design manager. Management reports provide him input on current status of all elements of the ship design with the addition of cost analysis information from systems engineering.

The ship cost goal is stated in the draft TLR developed around the CBL and applied in making design decisions during preliminary design. The TLR, issued at the end of preliminary design, states a ship cost constraint to be applied during contract design through the application of configuration control. Table 5 summarizes cost estimating tools, their development, and use in ship design.

TABLE 5
OVERVIEW OF COST IN THE SHIP DESIGN PROCESS

Costing Tool	Development	Application	Purpose
Marginal shipbuilding cost factors	Conceptual design phase	Conceptual design and early preliminary design	Systems design tradeoff data regarding cost impact of system changes on ship
Ship acquisition cost model	Conceptual design phase	Preliminary design	Ship cost goal tracking during design and large scale tradeoffs
Ship operation cost model	Conceptual or preliminary design phase	Continuing	SHAPM life cycle cost estimation for program appraisal
Detailed ship cost factors	Preliminary design phase	Late preliminary design and early contract design	Configuration control and detailed design decision

Cost estimates, as outlined in this table, are made in support of ship design project management and the SHAPM. Reports documenting the costing tools are restricted to project management, SHAPM, and NAVSEA cost estimating concepts for marginal cost factors which are broadcast to all design participants for their tradeoff use.

HFEI and the Ship Planning Design and Acquisition Process

Implicit in each of the previously discussed stages of the total ship process are HFE requirements to which the HFEI project will be responding. In the following portion of this report, these stages are listed, the implications regarding HFEI identified, and the HFEI analyses required will also be listed.

Prefeasibility Stage

Design Events and Decisions

- Define operational requirements.

- Select a platform type conventional monohull displacement type versus one of the several alternatives (hydrofoil, SES, SWATH, multihull, etc.).

- Establish a "ballpark" size.

Implications for HFEI

Operational requirements and platform type and size all have a first order effect on the human operator-maintainer. The HFEI specialist needs to be concept oriented.

HFEI Analyses Required

- Manpower consideration to support: operational needs, concepts, goals, and size.

- Platform motions and effects on humans.

- Assessment of scenarios, tradeoffs, risks, costs, and gross system optimizations to ensure they are user oriented and compatible.

- Structure criteria for people-inputs to nontraditional ship design methodology which can be developed at this stage.

Feasibility Stage

Design Events and Decisions

- Define a series of feasible ships, with associated production costs, which meet, or approach, initial performance requirements.

- Achieve a balance between operational requirements (based on companion military effectiveness studies) and production costs (i.e., to determine most operationally cost effective alternative).

● Select, from the alternatives defined, a ship for conceptual design ("concept selection").

● Assure definition of alternative ships to the level required for a class E* (class F** for less reliable results) cost estimate.

● Identify the major technical risks associated with alternative ships.

Implication for HFEI

The design aspects of this stage can be characterized as addressing primary payload and performance features (speed, endurance, protection, etc.). Analyses of the payload and performance, as well as cost, are very limited in their scope and definition if they do not include people parameters. A conceptual orientation is also needed here.

HFEI Analyses Required

● Designer and management oriented listings of trade-off criteria for manpower, automation, life support, costs, habitability, space allocation/arrangements, propulsion, machinery, and weapons/sensors.

● Structure inputs to ILS policy.

● Provision of technical inputs to synthesis models, inputs to R&M philosophies, and inputs to T&E plan.

Concept Design

Design Events and Decisions

● Provide a technical base line (CBL) for DSARC I (Defense System Acquisition Review Council decision for program initiation) for new major combatant or developmental designs.

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*Class E - Computer Estimate
An estimating process when cost and design information are developed by use of a computer model which grossly determines ship specifications from a given set of input characteristics. In general, the output cost and design information are calculated from estimating relationships through a series of equations while pay load-type items such as electronics, ordnance, etc. are costed by a shopping list technique within the model.

Present applications of this type of cost estimate are for parametric cost studies, where relative costs and not absolute costs are primarily considered, and for estimates of ships which are in the conceptual design stage.

**Class F - "Ball Park" Estimate
Quick cost estimates are those prepared in the absence of the minimum design and cost information package and are based on gross approximate parameters. Typically, estimates are calculated by merely escalating to current dollars an empirical cost for a similar ship and adding factors for expected changes in design, accounting procedures, or other economic considerations.

● Assure definition of the ship to the level required for a class D* cost estimate (provides a basis for setting a design-to-cost goal by OPNAV).

● Validate feasibility study results, provision of a firm base line for initiation of preliminary design (size, weight, and cost should only be "reduced" in preliminary and contract designs).

● Make initial resolution of major technical risks identified in the feasibility studies.

Implications for HFEI

The seakeeping behavior has been generally defined at this point; however, some hull form and weight distribution changes may take place along with the introduction of motion stabilization systems. This is a validation, assurance, initial risk resolution stage. HFEI criteria should be positive, and valid predictive inputs for feasibility studies should be used. The HFEI specialist should participate as member of concept design team, be concept oriented, and be familiar with the Navy design process.

HFEI Analyses Required

● Provide contributions to the CBL for new major combatant or developmental designs.

● Prepare simplified prediction tools/methods and inputs for use in ship synthesis computer models (continuation/same as feasibility stage).

● Provide criteria for tentative subsystem selection lists (weapons, electrical, machinery).

● Provide tradeoff criteria useful in preparing tentative equipment list.

● Provide command control communication criteria useful in topside arrangement.

*Class D - Feasibility Estimation
An estimate of a lower quality than a class C estimate due to an insufficiency in the design, procurement, or cost information primarily the result of a need for an estimate before such information can be further developed to justify a C classification. Such early estimates are usually exploratory in nature and are prepared to perform tradeoffs and cost effectiveness analysis, to establish notional ship characteristics, and for costing the program objectives in the out-years where there is an absence of sufficient design development.

Generally, the primary design input for a class D SAIC estimate will be feasibility and cost study characteristics (single sheet), as opposed to the SAIC approved characteristics included in class C estimates. Cost estimates derived solely by a plus and minus technique from a higher quality estimate or from a repeat design where SAIC guidance on the project deletes or adds characteristics which have a potential impact of significantly altering the design configuration are considered to be a feasibility estimate due to the lack of sufficient design development.

● Provide inputs to top level requirement in areas of maintenance and supply concepts, manning, habitability, life support.

● Provide inputs to special analyses in high risk areas.

● Provide inputs to cost analyses.

Preliminary Design Stage

Design Events and Decisions

● Provide a technical base line (FBL) for DSARC I or II. DSARC II is the Defense System Acquisition and Review Council decision for full-scale development. DSARC I was previously defined.

● Assure definition of the ship to the level required for a class C* cost estimate (lowest budget quality estimate).

● Achieve a complete engineering description of an integrated ship system such that the basic ship size and definition will not change during contract design.

● Achieve functional definition of integrated subsystems selected for optimization of total ship performance and cost.

● Select final design criteria for whole ship entity characteristics such as noise and ship protection consistent with cost and performance optimization of the total ship.

Implications for HFEI

In a sense, this stage is the "core" of the ship design process. At this time the engineering tradeoff studies are made in the areas of electrical power, hull form, major structure, weapons/sensors, and general arrangements. Now the subsystem functions are defined, and the characteristics of ship systems are established. It is the analytical stage not only for the designer, but also for the HFEI specialist who must now provide quantitative descriptions and criteria to the designer. This is a "heavy work load" stage for the HFEI specialist in that detailed integration now occurs for him. He now cuts across the whole ship in terms of functions, definitions, and selections because the roles of the operators/maintainers are being specified.

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*Class C - Budget Quality Estimate
These are considered to be the highest level of cost estimates attainable in the planning, programming, and budgeting process since the more extensive class A and class B estimates are considered post-budget estimates. A class C estimate is recommended level for estimates of cost to be used in the budget submission especially at the Congressional level, preferably for the NAVCOMPT and OSD/BOB submissions and whenever feasible for the program objective estimates for the current year.

HFEI Analyses Required

● Prepare HFEI plan and schedules to define the human tasks and man-machine interfaces not only with equipments but also with functions and systems/subsystems. The plan will be integrated with all other design efforts.

● Prepare engineering design criteria and technical input for design studies/analyses in the following areas: preparation of: Master Equipment List (MEL); Ship Manning Document (SMD); Reliability, Maintainability, Availability (RMA), general arrangements, space arrangements, access studies, habitability, life support, seakeeping (motions), machinery arrangements, safety, all control studies/analyses and all system descriptions (combat, command, control, communications, etc.).

● Provide technical inputs to planning documents such as: ILS plan, T&E master plan, and the combat system management plan.

● Provide appropriate inputs to the TLS and TLR to the cost estimates and to the FBL drawings and reports.

Contract Design Stage

Design Events and Decisions

● Provide a technical/contractural base line (ABL) suitable for DSARC II or III. DSARC III is the Defense System Acquisition and Review Council decision for production.

● Assure definition of the ship to the level required for a class B* and/or class A** cost estimate (validation of "design-to-cost").

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*Class B - Bid Evaluation Estimate
An estimate prepared to validate the "reasonableness" of cost estimates received from contractors or government shipyards. Prepared immediately prior to a bid opening or upon receipt of an initial cost estimate from a naval shipyard.

The scope is similar to a class A cost estimate except that the estimate is not as detailed. Unlike the class A detailed cost estimate, material quotations are not necessarily obtained from industry and the cost estimating relationships used reflect a higher degree of aggregation.

**Class A - Detailed Cost Estimate
An extensive cost estimate prepared to validate an end cost estimate, for determination of a "fair and reasonable" price for comparison to contractors prices, but primarily for contract negotiation purposes. It is always prepared in the post-budget process and generally prior to a bid opening or scheduled negotiation of fixed price incentive or cost plus type contracts. This level of cost estimate requires contract plans and specifications and a detailed contract design weight estimate as inputs from the design process.

The cost and economic inputs are primarily unit material and man-hour cost estimating relationships developed to the NAVSHIPS Consolidated Index of Materials breakdown (3 digit level) of costs, vendor quotations for all major material items and a thorough analysis of the competitiveness of the market, expected labor and profit rates, escalation, etc.

Due to the extensiveness of the estimate, requiring in excess of 5 weeks of development and calculation of data, this type of estimate is only prepared when conditions so warrant such a level of detail.

● Translate completely the FBL "engineering" definition of the ship to a contractual "biddable package".

● Validate in general FBL ship system and subsystems through increased level of definition.

Implications for HFEI

This is the most critical stage in the total ship process. Up to this point it is assumed that the navy planners and designers have "produced" a ship in which the crew and the vessel function as a well integrated total system. The problem now becomes how to translate that integrated completeness to the shipbuilder so that the resulting product will not only fit the "cost picture" but will be operationally effective. The HFEI specialists in this stage must be aware of, and familiar with, the production process so that his HFEI specifications and requirements are practical, clearly defined, and well within the design-to-cost concept.

HFEI Analyses Required

● Prepare a plan and schedule of HFEI participation integrated to other contract efforts.

● Review and validate prior HFEI contributions.

● Review and validate subsystem configurations regarding human components.

● Review and validate system level performance tests and assessments regarding human components.

● Prepare criteria for detail layouts of vital spaces.

● Prepare technical inputs to planning documents for design and construction stages.

● In support of the HFEI plan provide a description of the human subsystem and its relation to the total ship as well as other subsystems.

● Prepare a list of appropriate reference documents and military specifications.

● Prepare required mock-ups; evaluate and validate operator/maintainer interfaces with equipments, HFEI interfaces with safety, reliability/maintainability, manning, communications, etc.

● Identify contractor required modk-ups and their demonstration or use.

● Prepare sections of ship specification and review of total ship specification.

- Prepare guidance and criteria for contract drawings.

- Prepare input to ILS and T&E plans.

- Prepare a Contract Data Requirements list.

- Prepare a list of special studies required by contractor.

This effort has resulted in a base line discussion of the HFEI project with regard to the total ship planning, design, and acquisition process. Certain analyses presently required by HFEI in each of the major phases of that process have been identified. During the evaluation of the HFEI project, the total ship process will be reexamined in more detail so that the planned HFEI contribution will be practical, well defined, and proven through demonstrations to be of benefit to the total ship process.

As this new HFEI technology is being developed, any technological gaps relating to the ship process will be identified and assessed. If those gaps are found to be of value to the ship process, then appropriate documents will be prepared recommending the development of a technology base.

BOEING AEROSPACE CO.

One of the initial programs in ADO 43-13 was the CAFES program. CAFES is a computerized system to aid in accomplishing HFE functions for design, development, and operations of man-machine systems, primarily air systems. Work on this program was performed by the Boeing Aerospace Company, Seattle, Washington, which reported results in 1975.[4]

During the first year that HFEI became a part of ADO 43-13, it became apparent that the two programs (HFEI and CAFES) should interface with each other to reap mutual benefits. Therefore, in January 1975, Boeing Aerospace Company was tasked to provide an adaptation of CAFES to ship systems development. At the conclusion of the task Boeing submitted a report[4] describing the following five submodels of CAFES and their possible applications to ship system design.

- FAM - Function allocation model

- DMS - Data management system

- WAM - Workload assessment model

- CAD - Computer aided crew station design model

- CGE - Crew station geometry evaluation

Boeing used actual human engineering tasks on a new ship development, the PHM ship, to exemplify CAFES usage. Unfortunately

these examples of CAFES potential were not adopted because overall PHM program constraints did not allow full implementation of a comprehensive HFE plan. CAFES concepts and capabilities are described and synopses are provided as to how those capabilities could have been used to assist PHM development. CAFES potential applicability to any ship development is also discussed and suggestions for further study are offered. Boeing identified the following six PHM-specific tasks to which CAFES could have been applied; these tasks are common to any ship program.

- Determination of total crew size and crew composition.
- Determination of the number of seats at evaluator station.
- Determination of the location of display indicators for critical functions.
- Calculation of the external vision from the pilothouse.
- Calculation of the seat adjustment ranges for the engineer's operating station and combat information center.
- Consideration of personnel and training.

The HOS was also identified by Boeing as a tool with potential applications to ship systems development. HOS is a digital computer program that provides a generalized model of a seated operator in a crew station and is being developed for use with the submodels of CAFES or independently as a final design-validation tool.

WALTER DORWIN TEAGUE ASSOCIATES, INC.

The report submitted by Teague Associates describes the field of industrial design engineering and the approach that industrial designers take in evaluating and applying technology to problems similar to those found in the ship design process. The report also includes a discussion of the implementation of industrial design in the weapons system development cycle and a few pertinent current examples of the interface between industrial design and HFE. The report defines industrial design as a multifaceted discipline concerned particularly with aesthetics such as style, appearance, enhancement, form, fashion, etc.

The techniques used by the industrial designer in the design process follow an activity which is basically one of "synthesis." The importance of investigative methods in the design process are stressed as the first and most important portion of this synthesis for the industrial designer. This

activity and the techniques used by industrial designers are illustrated by reference to different design stages. In a preliminary design phase the designer's role is stated as employing imagination in the search for solutions to problems. In addition, the designer expresses imagination through the use of tools such as foam-core mock-ups, scale models, or drawings. In prototype testing, fabrication methods and techniques are used to uncover discrepancies before production and field testing are undertaken. In the final or productive design development phase of a product, the industrial designer evaluates necessary changes, prepares final art work, and specifies materials and color recommendations. The creative, aesthetic aspect of the work of industrial designers follows a logical sequence that could contribute to future naval design decisions in areas such as habitability and man-machine interfaces. The Teague report states that industrial design should have its most important effect in the conceptual development and preliminary configuration planning of systems such as a Navy ship system. In these early stages of design the industrial designer is faced with a role and structure similar to that of the human factors engineer.

Some of the industrial design technology which can contribute to HFEI should be considered for impact on the naval weapons design process, especially in the development of shipboard environments. The admixture of safety, efficiency, and reliability; as well as morale and pride in one's ship, would seem to be a very positive aspect of the application of the creative design solutions offered by industrial designers.

ESSEX CORPORATION

As the integration contractor for the HFEI project, Essex Corporation submitted a report,[6] which included an initial assessment of commercial shipbuilding HFE practices, reviews of current HFE related technologies, a first approximation of the technology, and a proposed project plan to be followed during 1976 - 1979.

Information concerning the assessment of commercial shipbuilding HFE practices resulted from an analysis of USS SPRUANCE (DD 963) HFE plans and programs, plus the experience of Essex Corporation personnel in applying HFE technologies in commercial shipbuilding yards. The Essex report states that the questions of importance in this assessment were not those directly related to whether or not commercial shipbuilders were acting in compliance with the ship planning and acquisition process demands and constraints; rather it was oriented toward a description of what had been commercially defined as HFE technology and was being applied in response to these demands and constraints. The DD 963 (USS SPRUANCE) was selected as the target ship for two reasons:

● The desirability of basing the assessment on an HFE plan for a surface ship which had been approved by the Department of the Navy and proceeding from an examination of that plan to a determination of what actually occurred in the implementation process.

● It would provide a base ship for analyzing the classes of HFE problems involved in a current ship development program.

The original Litton Systems, Advanced Marine Technology Division (AMTD) proposal for the DD 963 was contained in 11 volumes. Essex reviewed those 11 volumes and a summary of that review follows. The proposal demonstrated that the human factors effort at Litton was responsible for:

● Development of operator/maintainer information requirements and operating procedures.

● Human factor inputs to definition and detail design, i.e., work on the habitability of system work environments and personnel support facilities.

● T&E - to verify that design of equipment, procedures, work environments, and facilities meet human performance, habitability, and life support requirements and are compatible with overall system requirements.

Specific program objectives were:

● To develop contract definition design features in critical equipment.

● To develop procedures with minimum manning, skill, and training requirements.

● To identify and eliminate human error.

● To verify design characteristics, procedures, documentation, manning allocation, and training.

● To apply human factors to identify and minimize hazards.

● To apply research and study techniques of human factors to identify unusual problem areas and develop satisfactory problem solutions.

The Essex report further stated that a system engineering approach was promulgated by Litton Systems Engineering and Human Factors Department personnel to define the technique for the phase A DX proposal of the DD 963 and to lay the ground rules

for refined analyses in the phases of ship design that would follow. Litton's systems approach provided an integration of work study techniques, MIL-H-46855 principles, and Litton proprietary analyses techniques. During this definition stage the following five analytic areas were designated: requirements, design analysis, decision, design evaluation, and results. A simplified flow of the approach is shown in figure 4, DX Systems Engineering Summary.

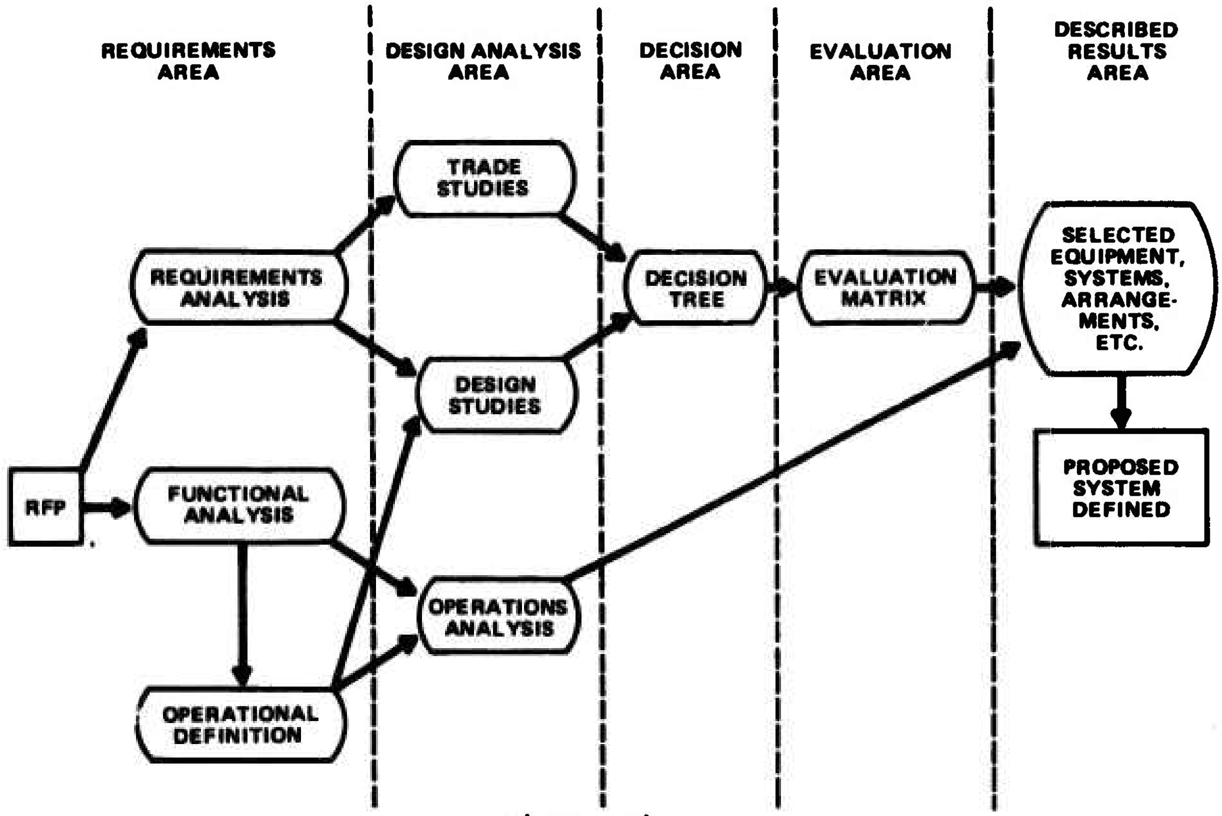

Figure 4
DX Systems Engineering Summary

This approach provided a means of technically controlling and coordinating a contract definition engineering effort; an effective tool for performing system integration; and flexibility in systems definition in that systems may be defined from the COR's functional requirements or combinations of the two.

Figure 5 shows a detailed flow diagram of the systems engineering approach used during the DX Systems engineering.

The initial step in the Litton approach was the determination of requirements and the translation of those requirements into subsystems, equipment, manning, and arrangements.

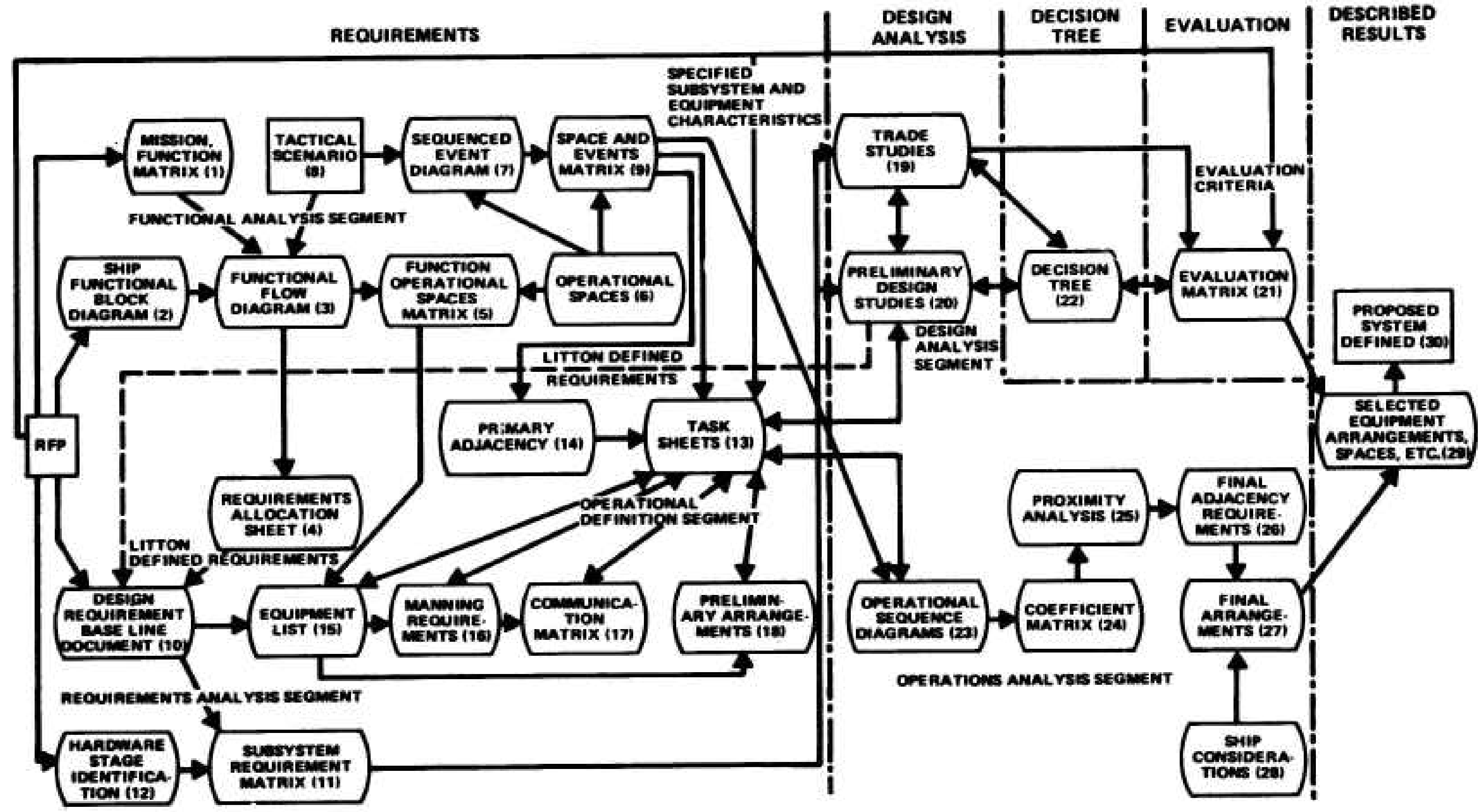

Figure 5
Detailed Flow Diagram for DX Proposal

The approach was divided into five major segments: functional analysis, requirements analysis, operational definition, design, and operations analysis.

The human factors program requirements were defined in the "Human Factors Specifications for the DD 963 Class Ship," a Litton document. The human factors plan for the ship described the human factors program including associated tasks and procedures to be implemented during the development and production phases. The human factors tasks were essentially divided into four areas: human factors analyses; human engineering design; special studies; and human factors test and evaluation. Essex included a brief description of each of these areas with the tasks identified for each area and their inter-relationship.

The information presented on the DD 963 is considered accurate but not complete or fully validated. Plans are to validate the DD 963 information during 1976, by utilizing a structured interview guide developed by Essex.

The Essex report also contained a review of some of the current technologies relating to HFE. That review was limited in scope to the technical inputs from other HFEI project participants and summary reviews or investigations of other related efforts and other technologies. This latter effort included brief examinations and reviews of the objectives, plans, and products of other 43-13 projects (Human Factors Test and Evaluation, Human Reliability and Air Combat Performance Criteria, and brief analyses of the technologies of manpower, personnel and training, medical and life support.

The Human Factors Engineering Test and Evaluation Methodology project will encompass the development of:

- A T&E methodology adaptable to system requirements which will allow for appropriate HFE data to be collected during partial performance testing or in an integrated manner to provide an overall assessment of a system under a variety of conditions.

- A feedback system for the meaningful translation of test and evaluation findings into R&D requirements and/or training requirements, i.e.:

  - Assessment of HFE design criteria to determine unsubstantiated or poorly substantiated areas.

  - Development of standardized reporting requirements for HFE T&E results (e.g., types of data, format, etc.).

• A T&E package comprising a logically branching HFE checklist which allows for combining of "simple" discrepancies into generic problems which must be faced by system designers and training personnel.

Efforts to define and apply HFE in the T&E process are underway at the Pacific Missile Test Center (PMTC). One of the recent PMTC publications has translated Defense Systems Acquisition Review Cycle (DSARC) milestones into HFE requirements. PMTC also has a number of technical information papers completed or in process which will cover T&E technologies, including the effect of variables such as noise, temperature, and vibration on performance. There are three principal areas of T&E with each recognized as having some unique requirements pertinent to HFE.

- Development Test and Evaluation (DT&E). Various types of development tests are used to identify potential design problems and to derive data necessary for the solution of known critical development problems. Included are breadboards, prototypes, static mock-ups, dynamic simulation models, and qualification tests. These tests are conducted on board other class ships or at land-based test sites since ship programs may be large, complex, and of prolonged evolution.

- Operational Test and Evaluation (OT&E). The test and evaluation effort in the area of OT&E is directed toward obtaining information throughout the life-cycle of the system and supports both the acquisition process and the optimal employment of the system.

- Acceptance Trials. The Board of Inspection and Survey is responsible for conducting trials of new ships prior to Navy acceptance from the contractor. HFE activities obtain maximum verification data and evidence of personnel errors, human-assisted malfunctions, and man-equipment/system interface deficiencies by exercising individual or multiple ship subsystems in dynamic and static sea conditions.

The objective of the Human Reliability Prediction System project is the development of a technology for the prediction and demonstration of system effectiveness parameters for combined man-machine systems as well as their application. Parameters such as mission reliability and availability, as well as designer-oriented measures such as reliability (e.g., MTBF) and maintainability (e.g., MTTR) are considered. This work is being conducted under the auspices of COMNAVSEASYSCOM (SEA 06H1-3).

The technical approach consisted of three phases: first, development of a technology to provide the required individual human reliability inputs; second, development and validation

of a combined man-machine prediction and demonstration technology; third, formulation of the technology to facilitate application. The end-products from this program will include a model of maintenance technician reliability as well as a model of operator reliability for electronic and electromechanical systems.

A potentially valuable result of this effort is the development of a ten-man reliablity model in place of the more often used one-man reliability models. The ramifications of a multiman reliability model to ship systems is obvious since the technological systems on board Navy ships are the result of an interaction of many men. A bibliography of 22 articles that form a foundation for the Multi-Man Reliability Prediction is contained in NAVSEA document 06H2-71/KPL 9460 SER 201, 22 July 1975.

The Air Combat Performance Criteria project has as its objective to develop realistic data from operator in-flight performance to predict performance under varying conditions of aircraft characteristics, mission objectives, and maneuvering requirements. This will result in improvement to pilot selection criteria, training techniques, aircraft design, and operational processes and techniques. This work is being accomplished at the Naval Aerospace Medical Research Laboratory, Pensacola, Florida. The approach will examine the following three areas:

- Air to Air Visual Target Acquisition. Early visual acquisition and tracking of targets is a crucial element for tactical advantage in air combat. Variables critical to air-to-air visual acquisition will be investigated, and methods of improving performance during this mission function will be demonstrated.

- Radar Intercept Officer (RIO) requirements. Wide individual differences exist among naval flight officers regarding their abilities to perform as radar intercept officers. This development will identify capabilities required for the RIO intercept mission function, criteria for predicting these capabilities, and special training requirements.

- Air Combat Maneuvering Performance. A first task here is to develop a technique of recording in-flight operator performance criteria. Other tasks will include development of aircraft design criteria for enhancing air crew operational performance processes and techniques. All of these developments will then contribute HFE data, technologies, and capabilities as inputs to a Naval Air Systems Command Warfare Specific Applications and Integration project.

An initial examination of manpower, personnel, and training technology was one of the tasks undertaken by Essex. A minimum

effort was expended to prepare the following broad coverage of manning as it relates to the ship design process.

• The Personnel and Training Analysis Office (PATAO) NAVSEA (SEA 04H) plays a significant role in determining Fleet manning requirements. PATAO constructs SMD for many diverse platforms. The SMD is based on thorough descriptions of the equipment on board and is aimed at arriving at the best match of men and equipment. The techniques that PATAO uses to compile the SMD are largely manual and rely on the group's broad experience base as well as referral to general specifications for ships of the U.S. Navy. The SMD is dependent upon accurate watch, quarter, and station bills. These doduments are used to show how each member of the crew is assigned to allowable lengths of productive work, sleep, leave, training, etc. All of this information helps to detail the total crew time allocations for major functions within each condition of ship readiness. To fulfill other manning responsibilities, PATAO develops job and task descriptions using techniques such as operational sequence analysis, work flow analysis, function analyisis, and task analysis.

The PATAO group often gathers information from operational personnel by means of questionnaires. This information may be supplemented by the examination of various operational scenarios to make manpower requirements predictions. The PATAO analyses also address life-cycle costing, where personnel costs based on DOD and Labor Department statistics are used to examine such issues as tradeoffs between military versus civilian labor costs and benefits.

• The Naval Ship Engineering Center (NAVSEC) maintains and uses the MDM. This computer model permits design engineers to obtain ship manning information and life-cycle cost estimates during the early phases of the design cycle. An MDM derived estimate of manning for existing ships when compared to actual promulgated SMDs indicated that the MDM has an accuracy of $\pm 5\%$. The MDM was used in 1968 to establish a manning base line for the DX program (Plato, 1974).

The MDM predicts manning for a new ship by referring to subsystem/equipment manning "modules" based largely upon actual Fleet information, up-to-date subsystem/equipment information, or data developed through the design work study process. The heart of the MDM is the manning program which selects and uses hull, propulsion, and payload systems modules for a new ship from modules in a master index file. Determination of the cross-utilization of selected system personnel is accomplished next. After this, the program assesses the overall number of officers, chief petty officers, and other enlisted men required for the hull, propulsion, and payload systems. The program then automatically selects the appropriate administrative and support subsystem modules for the ship with consideration

of the cross-utilization of these personnel. After this step, the program proceeds to print out a document similar to a watch, quarter, and station bill.

To construct the MDM library, data were collected aboard 10 DE, DD, DDG, and DLG class ships. The MDM data bank has been expanded to include DLGN, LPA, LKA, AE, AF, AO, AOR, MCS, CVA, and CVAN class ship information. In addition, programs have been developed for new system/equipment modules; for example, the MDM data bank contains information on close-in weapons system (CIWS), 5-inch/54 lightweight gun, and gas turbine propulsion subsystems.

The Navy project plan for the development of the first approximation of an integrated technology did not include a specific task assignment in the medical and life support areas in FY 1975. This Center's plan is that these areas would be extensively reviewed, assessed, and integrated beginning in FY 1976. With the concurrence of the technical agent, a minimal effort by Essex Corporation personnel was expended to explore these areas and to examine some of the requirements and available capabilities or approaches to developing improved and/or new capabilities.

The first Technology Coordination Paper on the Medical and Biological Sciences (DDR&E, 1971) pointed out that three general categories of operational problems cause the loss of combat strength. The three categories were described as follows:

- The standard medical problems of disease, wounds, and climatic disease — the major killers and cripplers of forces in the field throughout military history.

- The maintenance of man in the machine environment. As warfare and weapons have become increasingly mechanized, the ability of the machine to survive in environments and operations normally lethal to man has forced man to adapt to, or be protected from, the machine-environment interaction. In high speed aircraft, acceleration and impact forces degrade human performance; in nuclear submarines the sealed environment poses unique toxic hazards. The heat, noise, and vibration in armored fighting vehicles have specific deleterious impacts on man. Neither human evolutionary development nor the provision of safety and survival devices have kept pace with the ability of the engineer to build evermore complicated weapons. This area of military medical research is increasing in importance as a cause of casualties. Failure to engineer for the human component of the system is usually accompanied by the loss of the man as well as of expensive equipment.

• Finally, there are problem areas which are important to the health and well-being of the fighting man and which contribute critically to his protection from special hazards and the maintenance of his effectiveness in doing his military job. Among these research areas are radiation effects, neuropsychiatry, nutrition, toxicology protection, and protection of this food and material from biological degradation.

Navy Medical and Life Support RDT&E and Operational Medicine programs encompass within their programs a wide range of objectives which relate both directly and indirectly to surface ship planning, acquisition, and operations. The following examples of specific capabilities and new technology developments are considred of particular significance to ship planning, acquisition, and operations:

• Heat stress data system development and instrumentation for measuring heat stress, e.g., the Physiological Exposure Limits Chart and the Heat Stress Meter.

• Protective procedures and equipment against high intensity microwave and radio frequency fields of various wavelengths, LASER beams of various wavelengths, high intensity sound and magnetic fields associated with radar, communications, and other electronic equipment.

• Shock hardening modifications for vital medical equipment aboard ships.

• Practical, economic sterilization of ship's sewage disposal system; virus removal by sewage disposal processes; use of ultrasonics in resolving these problems.

• Decontamination of ship's interiors and ventilation systems to prevent and/or control the spread of airborne infections.

• Fleet casualty care systems for efficient diagnosis, treatment, and management of casualties among naval personnel engaged in Fleet operations.

• Effective system of providing hearing conservation services to naval shipboard personnel; revisions to damage risk criteria.

• Incidence data management system on Fleet illness and injury not requiring hospitalization on surface ships.

• Localizing and developing controls for toxicity effects of propellants, explosives, and pyrotechnics.

• Resolution of vibration effects, including explosion-shock and slam, on crews and inherent equipment and the

evaluation of surface ship platforms as to suitability for casualty transfer; assessment of ship design engineering criteria and practices related to the above factors.

- Visual and auditory performance enhancement under conditions of environmental stress and fatigue; nausogenic motion.

This discussion of Medical and Life Support Considerations in general, and specifically with regard to surface ships, is very preliminary in nature. Nevertheless, it invites attention to what are considered as important, high priority requirements and technologies, as well as technology gaps, which need to be considered in the planning and acquisition of Navy ships and in planning RDT&E programs for meeting the requirements of these ships.

The above listing of examples indicates the need for further development of a taxonomy suitable for cataloging medical and life support requirements, functions, and technologies specifically related to surface ships. The FY 1976-1979 plan presented elsewhere in this report includes proposals for extending this preliminary examination into a comprehensive description, analysis, and integration of the medical and life support areas as related to the ship planning and acquisition process.

The general strategy employed by Essex for the development of the first approximation of an integrated HFE technology involved a description, analysis and a proposed structure for assessing and integrating a technology base which can be applied to the multidisciplinary requirements of the ship planning and acquisition process. That strategy includes information on:

- The total ship planning, design, and acquisition process described in fuctional terms including HFE functions, requirements, and end-products.

- The characteristics of a recently-developed Navy ships (DD 963) and the HFE plan for that ship abstracted from commercial shipbuilding sources.

- Human factors engineering and other related technologies selected by the Navy sponsors and reported on by Navy or contractor participants in the HFEI project.

- Technologies being developed under other advanced development programs such as HFE technology and manpower management and effectiveness.

- Development of an assessment and integration matrix and a preliminary demonstration of its use and potential.

The development of a descriptive model for the first approximation requires particular consideration to the following matters: the ship planning, design, and acquisition process is an evolving one and its full implications for HFE are not yet clear; only a limited assessment of the state-of-the-art in HFE has been possible during this first phase; and no final judgments will be possible until a more comprehensive review has been completed, and the various technologies have been fully assessed and tested through appropriate feasibility testing demonstrations.

Previous studies of Navy HFE programs were oriented toward such matters as organization, administration, qualifications of HFE specialists, directives, etc. Other efforts are technically oriented but are somewhat limited in scope and depth in terms of number of technologies and their integration. Unlike those efforts, this project's emphasis is on demonstrating how well (in quantitative terms) available technologies can support the ship planning, design, and acquisition process.

Several model concepts were considered for possible development as the base for the HFEI first approximation. It was decided that the attributes of the model best suited to the ultimate objectives of the Navy program were discussed in the DTNSRDC 1974 Workshop report.[1] The below-listed model characteristics, modified to some degree by Essex Corporation personnel, evolved from that workshop and describe a feasible model as:

- Compatible with the ship system development cycle.

- Meeting the requirements of the various HFE disciplines essential in ship design.

- Designed to deal effectively with both macro and micro level (e.g., platform and subsystem) developments.

- Recognizing the recurrent and reintegrative nature of HFE efforts.

- Rooted to system goals and emphasizes quantitative evaluation relative to ship readiness and effectiveness.

- Providing a monitoring capability to assess progress and termination or expansion of the effort when appropriate.

- Providing guidelines for allocation of HFE resources (personnel, funds, laboratory facilities, etc.) to meet ship development objectives.

- Assessing, compiling and accommodating the data bases, methods, and techniques of traditional and of new disciplines as required.

● Of most importance, providing direct support to program managers and naval engineers.

The model, in its most elemental form, brings together a number of HFE traditional and nontraditional technologies which are required for the solution of the multidimensional problems that arise in the planning and acquisition of naval ships. Figure 6 is an outline of the structural characteristics of the HFEI development process and shows the processes required to move from the present level of capability to one fully supportive of the total ship planning and acquisition process.

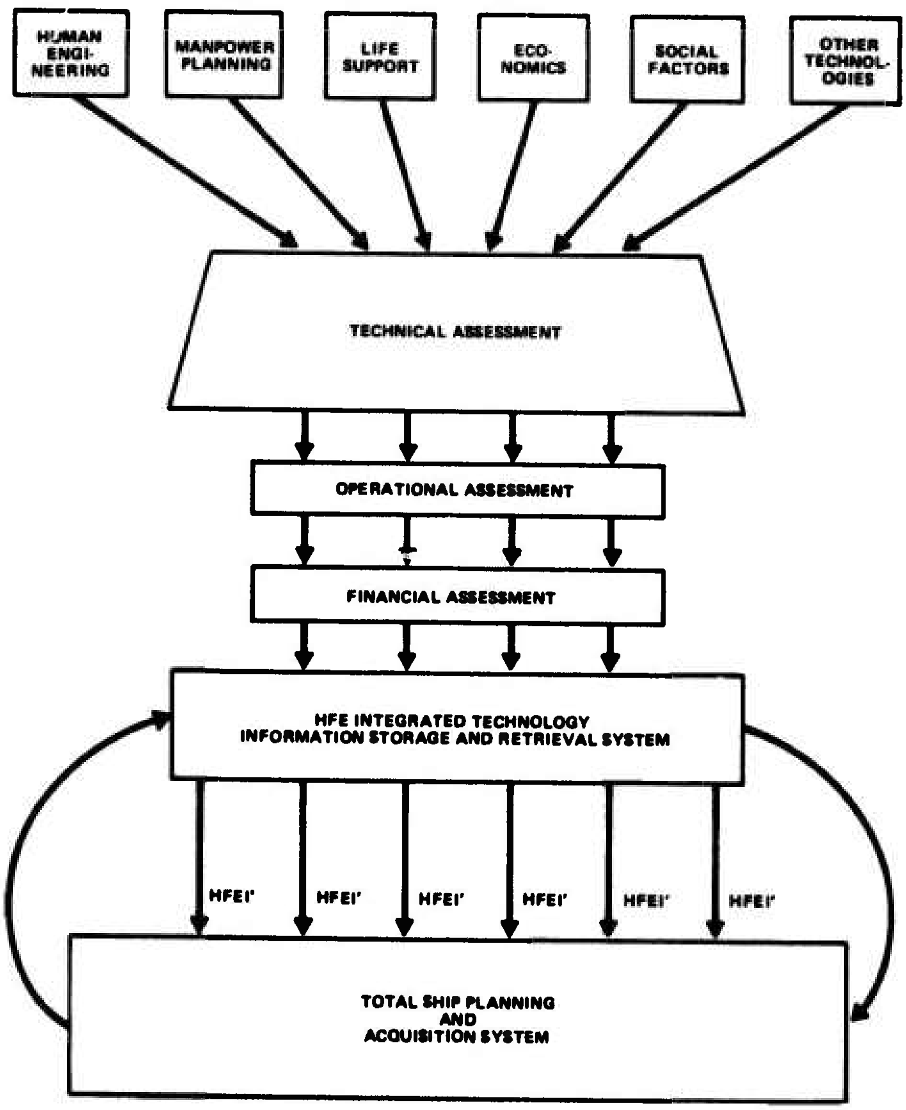

Figure 6
Outline of the Structural
Characteristics of the HFEI Development
Process

The application of HFE to the ship design process on a micro level presents another level of abstraction that must be dealt with by an assessment technique. An example can be seen in figure 7 where a summary representation of the ship planning and acquisition process is presented. The design stages on the outer ring have certain steps associated with them taht must be accomplished. Some examples of these steps are contained within the ring, while some of the individual human factors technologies that could contribute to the development of the steps are listed outside of the ring. Technologies such as these have individual characteristics that must be fully assessed. The definition, validity, and impact of some of the technologies are clear, while others are less lucid and have an impact across design stages.

The assessment technique will be further developed and updated as deficiencies are noted through empirical validation and will be applied to the technology base compiled as a result of phase II efforts. Some references, reviewing principles and progress in technology assessment studies have been collected for this effort.

GEORGE WASHINGTON UNIVERSITY

One of the participants in the HFE workshop of 18-19 June 1974 was Dr. Henry Solomon, Dean of the Graduate School of Arts and Sciences, George Washington University, D.C. Dr. Solomon is an Economist and he provided the workshop attendees with valuable information on the relationships between HFE and economics. Prior to becoming Dean, Dr. Solomon served as Chairman of the Economics Department at G.W.U. He has also been a consultant to the U.S. Navy for 20 years. With these credentials, he was tasked in January 1975 to provide the HFEI technical director with a profile of the field of economics including the tools, techniques, methodologies, etc., that have possible application to the solution of HFE problems.

The report that was submitted by Dr. Solomon at the conclusion of his task[7] emphasized the application of micro-economic analysis to resource allocation and utilization. Primary attention is given to the possible contributions of production and cost theory.

Dr. Solomon notes that the human factors literature as it relates to the production function contains a great emphasis on detailed microlevel combinations of men and equipment but little attention to the macrolevel HFE problems at the preliminary design stage. He points out that the formulation of the production function and associated notions should be of value in this regard, if the ship is viewed as a set of interdependent activities and cost functions are introduced.

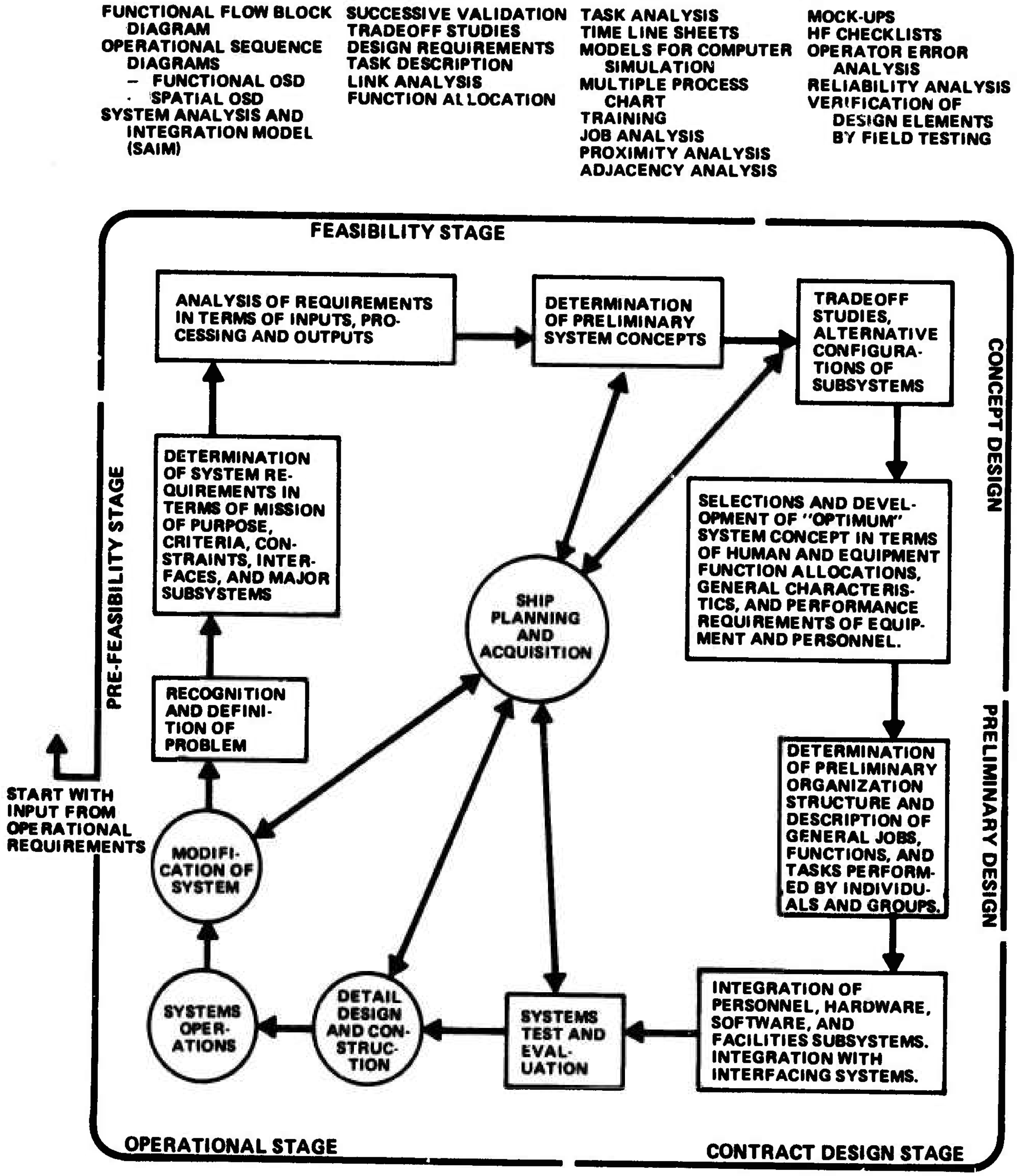

Figure 7
Summary Representation of the Ship Planning & Acquisition Process

Proceeding to a discussion of systems functions and costs, Dr. Solomon points out that cost analysis must be related to and, in fact, based up on the production function. His review of the human factors literature indicated that while some of the economic concepts of the production function are used, at times implicitly, even less analysis involving costs are considered. For example, where tradeoffs are considered, they are most likely to be technical tradeoffs. However, in many of the most important applications of human factors analysis, the appropriate objective is minimum cost combinations of men and equipment. Elaborating on available techniques (e.g., the Lagrangean multiplier) for use in cost minimization, and the conditions required for achieving this objective, he states that these conditions and others which come about in utilizing cost and production in the theory of the organization (e.g., for profit maximization) should be useful in human factors integration. However, he extends this assessment by stressing two priority needs for propositions which might be more useful for the present state-of-the-art in human factors integration. These needs are:

- Productivity measurements whether for technical evaluations or cost analysis.

- A completely specific production function.

With reference to the latter need, consideration should be given to whether training may be included as a factor input with its associated costs, or as not being within the ship's production function but as a contributing subsystem with the costs of training an individual being included in the price associated with the individual's service. He suggested that similar conditions may pertain to physical equipment when backup maintenance and repair costs are considered.

In addition to the identification of possible economic applications to HFE areas, Dr. Solomon reviewed some issues in the Litton DD 963 proposal for their economic impact in the area of HFE. On this issue he reports that the SMD used a "Bottoms-Up-Method" in which the design of the ship and the Navy's operational requirements are given and then the size and composition of the crew were determined. He notes the lack of explicit tradeoffs between equipment design, personnel, and operational requirements in the determination of billets and absence of even an attempt at estimating performance curves The output of equipments as a function of the number of operating personnel is a version of an "S" curve.

UNIVERSITY OF MARYLAND

Another participant in the HFE workshop of 18-19 June 1974 was Dr. Harriet Trader, Assistant Dean of the School of Social Work, University of Maryland, Baltimore, Maryland. Dr. Trader provided the workshop attendees with valuable information concerning crew systems dynamics (individual and group interrelationships) that relate to HFE. In addition to her duties as Assistant Dean, Dr. Trader teaches graduate courses in the School of Social Work and serves as a consultant to several agencies of the state and local governments in Maryland. Based on her accomplishments in these areas, she was tasked in January 1975 to provide a profile of the pertinent areas of crew system dynamics identifying the tools, techniques, methodologies, etc., associated with that technology and highlighting those that relate to HFE.

The report[8] that Dr. Trader submitted is based upon a survey of technology pertinent to individual and group interrelationships. She addresses problems and approaches/methods for solving the problems. An annotated bibliography of 49 reports pertinent to the issues and methodologies used in the profession is included in the report. The annotated bibliography documents articles which deal with sociology and modern systems theory, among others. She stresses the importance of social systems research and theory and the development of empirical models for approaching social problems. In addition, Dr. Trader discusses other major theoretical models as approaches to social problems. The details in the report provide a background for the use of these types of techniques and data in the pursuit of Navy objectives. Dr. Trader's report is a preliminary attempt to review methods available from the social sciences which may aid in the integration of social theory, data, and techniques into the HFE methodology so that individual and group influences in the Navy may be studied.

Factors that impact a complex societal structure such as would be found on a Navy destroyer are detailed in the report. Terms such as norms, conflict of institutions, and social mobility, among others, are explained in this report as a preliminary step toward their application to Navy issues such as race relations, alcohol and drug abuse, intra or intergroup communication, and morale. The distinctions brought out are potentially valuable and informative in providing cues to the structure of groups as they operate within the Navy. As examples, a method is discussed which can help clarify a conflict of value systems within groups; also a distinction is clearly made between nonconformity and aberrant behavior as they influence deviance from the values and norms of a society. It is shown that an individual conforming to one set of group norms or rules may exhibit nonconforming behavior in another group setting. Through an extension of these theoretical considerations factors such as nonconformity can be applied to Navy group structures to show how nonconformity can be viewed at times as beneficial and leading to constructive group change.

Eight models of approaches to the examination and modification of group processes are developed, covering a range of theoretical positions. Those models form the basis of a system for classifying social problems. These approaches to social problems are:

- Structural functional.
- Symbolic interaction.
- Cultural.
- Value conflict.
- Order versus conflict.
- Personal deficit.
- Social-psychological.
- Social work.

Dr. Trader emphasizes a social-psychological model as desirable for the attainment of goals similar to those found in the Navy since it examines both the individual and the group as distinct, yet interacting entities.

A discussion of research methodologies commonly used in the social sciences resulted in a nonquantitative evaluation of the following nine methodologies:

- Descriptive survey research.
- Needs assessment.
- Case studies.
- Developmental surveys.
- Correlational method.
- Case-comparative survey.
- Experimental design.
- Quasi-experimental design.
- Action research.

One specific methodology that is recommended as being potentially valuable to the Navy is the needs assessment method. It is a process by which needs are identified as they are related to social problems; priorities among needs are then determined, and recommendations for further action are made on the basis of priorities. Dr. Trader proposes that such a methodology would be extremely helpful not only in identifying the extent of social problems in the Navy but in the development of social planning to alleviate or solve problems.

NAVAL ELECTRONICS LABORATORY CENTER (NELC)

The Human Engineering Division at NELC was tasked to assess human engineering technology through a review of pertinent methodologies and an analysis of critical parameters related to ship system design. The analysis was based up on a number of studies which were reviewed.

The NELC report[9] included a preliminary and partial review of technologies potentially applicable to human engineering problems of command, control, and communications (C^3) systems. The review resulted in the identification and description of some 53 technology sources from the Human Factors Journal relevant to the HFEI effort. The original list of sources is contained in appendix 1 of the NELC report.

NELC also developed and applied a format for evaluating some of the material published in the Human Factors Journal. Fifteen articles were documented and assessed according to the format guidelines. The format included the following components:

- Title or identification.
- Source or agency which developed the method.
- References.
- State of development.
- Application (general/specific, place in the development cycle, platform designed for, whether applicable primarily to human engineering or to life support or personnel development.)
- Interrelationship with other methods (inputs, prerequisites, outputs, integration).
- Qualification and computerization.
- Costs (one time and recurrent).
- Ease of use.

- Advantages/benefits.

- Problems/limitations.

A separate bibliography of other human factors material compiled by NELC included ONR-sponsored research reports, DD1498 work units, symposium proceedings, technical reports from other activities, the Design Work Study handbook, annotated bibliographies, and texts dealing with human engineering methods.

One particularly helpful factor covered in the NELC report is the estimation of the cost of human engineering services. A matrix approach is illustrated for assigning costs by means of classifying subsystems versus discrete human engineering services of varying specificity.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations for this phase of the HFEI project are based upon a review of the planned technical inputs and products previously discussed. That review indicates that the following technology gaps require further research to accomplish the long-term integration goal of the project:

- Development of a system of data banks for human factors data and techniques is needed.

- Design handbooks dealing with anthropometry, weight-carrying limits, etc., need to be revised to include more dynamically based data, e.g., what are the projectile weight limits for ammunitions handling on a ship over a sustained performance period under realistic environmental conditions?

- The effects of various sea state conditions on human performance are not well understood or documented.

- The interaction of manning and economic factors should be more clearly formulated as they affect the design process and life-cycle costs.

- Survey methodology needs to be examined for its validity and reliability as applied to Navy social problems. Pilot tests of questionnaire items and techniques must be administered prior to use for sample polulations.

- Experimental designs, analyses, and field testing should more often employ multivariate analysis where appropriate.

- Multidimensional scaling techniques should be used with more regard to the validity and reliability considerations involved.

- Increased emphasis should be placed upon the validity and reliability bases of models and techniques.

- Modeling must consider multimeasurement approaches; e.g., time measures of an operator station must consider associated error rates; tracking scores must consider accuracy as well as time, etc.

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